

Worksheet 15B: Internal Energy, Adiabatic processes, Entropy, and Carnot

Objective G: Internal energy, Temperature and Mols $U = \frac{3}{2}nRT$

Problems:

1. What is the internal energy of 13.0 grams of Neon gas ($m = 20.1797 \text{ g/mol}$) that is at $45.0 \text{ }^\circ\text{C}$? (2550 J)
2. How many mols of an ideal gas would have an internal energy of 8910 J at a temperature of $25.0 \text{ }^\circ\text{C}$? (2.40 mols)
3. At what temperature in Celsius does 2.30 mols of an ideal gas have 34,500 J of internal energy? (930. $^\circ\text{C}$)
4. What is the internal energy of 153 grams of Argon gas at STP? ($m = 39.948 \text{ g/mol}$) (13,040 J)
5. At what temperature in Celsius does 15.0 mols of an ideal gas have 126,000 J of internal energy? (401 $^\circ\text{C}$)

Objective H: Pressures and volumes in adiabatic processes $PV^{\frac{5}{3}} = PV^{\frac{5}{3}}$

Questions:

6. Physically, how does a compressing piston heat up a gas?
7. Why does an adiabatic compression that cuts the volume in half, more than double the pressure?
8. Physically, how does an expanding piston cool a gas?
9. Why does an adiabatic expansion that doubles the volume, cut the pressure by more than a half?

Problems:

10. An ideal gas adiabatically expands from a pressure of 7820 Pa and volume of 4.50 liters to 6.70 liters. What is the new pressure? (4030 Pa)
11. 5.20 liters of an ideal gas is adiabatically compressed from a pressure of 12,400 Pa to 24,800 Pa. What is the volume after the compression? (3.43 Liters)
12. An ideal gas is compressed adiabatically from a pressure of 56,210 Pa and volume of 6.25 liters to 2.13 liters. What is the new pressure? (338,000 Pa)
13. 254 cubic inches of an ideal gas is adiabatically expanded from a pressure of 64.0 psi to 16.0 psi. What is the volume after the expansion? (584 cubic inches)
14. 12.0 cubic centimeters of an ideal gas is adiabatically compressed from a pressure of 242 Torr to 363 Torr. What is the volume after the compression? (9.41 cc)

Objective I: Entropy $\Delta S = \frac{\Delta Q}{T}$

Questions:

15. Why does the net entropy increase when a hot object comes to equilibrium with a cold?

Problems: (For water $L_f = 3.33 \times 10^5 \text{ J/kg}$, $L_v = 22.6 \times 10^5 \text{ J/kg}$)

16. A 145 g piece of iron ($c = 450. \text{ J/kg}^\circ\text{C}$) cools from $24.0 \text{ }^\circ\text{C}$ to $22.0 \text{ }^\circ\text{C}$. Estimate its change in entropy. (-0.441 J/K)
17. 45.0 grams of water freeze at $0 \text{ }^\circ\text{C}$. What is the change in entropy? (-54.9 J/K)
18. A Carnot cycle engine has an isothermal compression that occurs at $56.0 \text{ }^\circ\text{C}$ in which 14.0 J of work are done on the gas. What is the change in entropy of the gas in the engine, and what is the change in entropy of the low temperature heat reservoir? (For gas: -0.0425 J/K, for reservoir: +0.0425 J/K)
19. A Carnot cycle heat engine has an isothermal expansion that occurs at $352 \text{ }^\circ\text{C}$ in which the gas does 63.0 J of work. What is the change in entropy of the gas in the engine, and what is the change in entropy of the low temperature heat reservoir? (For gas: +0.101 J/K, for reservoir: -0.101 J/K)
20. 450. ml of liquid water boil into vapor at $100. \text{ }^\circ\text{C}$. What is the change in entropy of the water? (+2730 J/K)
21. 145 grams of water vapor condense to liquid water at $100.0 \text{ }^\circ\text{C}$. What is the change in entropy? (-878 J/K)
22. An 86.0 gram ice cube melts at $0.0 \text{ }^\circ\text{C}$. What is the change in entropy? (+105 J/K)
23. A Carnot cycle heat engine has an isothermal expansion that occurs at $651 \text{ }^\circ\text{C}$ in which the gas does 5120 J of work. What is the change in entropy of the gas in the engine, and what is the change in entropy of the low temperature heat reservoir? (For gas: +5.54 J/K, for reservoir: -5.54 J/K)
24. A Carnot cycle engine has an isothermal compression that occurs at $112 \text{ }^\circ\text{C}$ in which 11,400 J of work are done on the gas. What is the change in entropy of the gas in the engine, and what is the change in entropy of the low temperature heat reservoir? (For gas: -29.6 J/K, for reservoir: +29.6 J/K)

Objective J: Carnot cycle and heat engines

$$\eta_{\text{Carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}} \quad \eta = \frac{\text{useful work done}}{\text{energy input}}$$

Questions:

25. Outline the four processes that make up a Carnot cycle. Sketch it on a PV diagram.
26. Explain why isothermal processes cause no net change in entropy.
27. Why is an isothermal process hard to pull off in a timely manner?
28. Explain why adiabatic processes cause no change in entropy.

Problems:

29. A heat engine does work at a rate of 735 Watts, and radiates waste heat at a rate of 137 Watts. At what (Watt) rate does it consume energy? (872 W)
30. A Carnot cycle consumes 35.0 J of heat and wastes 23.0 J of heat. If the boiler is at 197 °C, what is the exhaust **temperature**? (Answer in Celsius) (35.8 °C)
31. A power plant operates at full Carnot efficiency. It consumes heat from the boiler at a rate of 985 Watts, and wastes heat at a rate of 421 Watts. It exhausts heat at a temperature of 97.0 °C.
 - a. At what (Watt) rate does this engine do **work**? (564 W)
 - b. What is the **efficiency** of this engine? (0.573)
 - c. What is its boiler **temperature**? (Answer in Celsius) (593 °C)
32. A heat engine consumes heat at a rate of 99.0 Watts, and wastes heat at a rate of 27.0 Watts. At what (Watt) rate does it do **work**? (72.0 W)
33. A Carnot cycle operates between 338 °C and 35.0 °C. What **heat** does it waste if it consumes 539 J? (272 J)
34. A power plant operates at full Carnot efficiency. It does useful work at a rate of 985 Watts, and wastes heat at a rate of 613 Watts. It has a boiler temperature of 572 °C.
 - a. At what (Watt) rate does this engine consume heat from the boiler? (1598 W)
 - b. What is the **efficiency** of this engine? (0.616)
 - c. What is the exhaust **temperature**? (Answer in Celsius) (51.1 °C)
35. A heat engine consumes 96.0 J of heat and does 53.0 J of work. What **heat** does it waste? (43.0 J)
36. A Carnot cycle operates at an efficiency of 32.0 % with a cool temperature of 53.0 °C. What is its boiler **temperature**? (Answer in Celsius) (206 °C)
37. A power plant operates at full Carnot efficiency between 86.0 °C and 665 °C. It consumes heat from the boiler at a rate of 8720 Watts.
 - a. What is the **efficiency** of this engine? (0.617)
 - b. At what (Watt) rate is **work** done? (5380 W)
 - c. At what rate is heat wasted? (3340 W)
38. A heat engine does 12.0 J of work, and wastes 25.0 J. What **heat** does it consume? (37.0 J)
39. A Carnot cycle operates between 426 °C and 91.0 °C. What is its **efficiency**? If it consumes 263 J of heat, how much **work** does it do? (0.479, 126 J)
40. A power plant operates at full Carnot efficiency between 93.0 °C and 378 °C. It wastes heat at a rate of 3610 Watts.
 - a. What is the **efficiency** of this engine? (0.438)
 - b. At what (Watt) rate does heat flow from the boiler? (6420 W)
 - c. At what rate is **work** done? (2810 W)
41. A heat engine consumes 95.0 J of heat and wastes 78.0 J. What **work** does it do? (17.0 J)
42. A Carnot cycle operates at an efficiency of 38.0 % with a boiler temperature of 641 °C. What is its exhaust **temperature**? (Answer in Celsius) (294 °C)
43. A power plant operates at full Carnot efficiency between 49.0 °C and 295 °C. It has a power output of 7820 Watts.
 - a. What is the **efficiency** of this engine? (0.433)
 - b. At what (Watt) rate does heat flow from the boiler? (18,060 W)
 - c. At what rate is heat wasted? (10,240 W)